7

CONFIDENTIAL

Copy No.
RM No. L9A24

NACA RM No. L9A24

NACA

RESEARCH MEMORANDUM

ANALYSIS OF THE EFFECTS OF VARIOUS MASS, AERODYNAMIC, AND DIMENSIONAL PARAMETERS ON THE DYNAMIC LATERAL STABILITY OF THE DOUGLAS D-558-2 AIRPLANE

By

M. J. Queijo and W. H. Michael, Jr.

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

CLASSIFICATION CHANGED
UNCLASSIFIED

To

By authority of NACA Res. abs. RN-115 Date 5-8-57 effective at 5-23-57

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
April 15, 1949

CONFIDENTIAL

NACA RM No. L9A24

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

ANALYSIS OF THE EFFECTS OF VARIOUS MASS, AERODYNAMIC, AND DIMENSIONAL PARAMETERS ON THE DYNAMIC LATERAL STABILITY OF THE DOUGLAS D-558-2 AIRPLANE

By M. J. Queijo and W. H. Michael, Jr.

SUMMARY

The effects of various mass, aerodynamic, and dimensional parameters on the dynamic lateral stability of the Douglas D-558-2 airplane have been investigated by means of calculations of the stability boundaries and the period and damping of the lateral oscillation. The results indicate that accurate determination of the stability derivatives, the radii of gyration, and the inclination of the principal axes are required if calculations of the dynamic lateral stability are to be of quantitative significance. Variations in the magnitudes of these quantities that might correspond to errors resulting from casual estimates may be very important.

An increase in the magnitude of the damping in yaw or an increase in the yawing moment due to rolling (in the positive direction) had a stabilizing effect in both the landing and high-speed configurations. An increase in the damping in roll had a large stabilizing effect in the landing configuration but a small irregular effect in high-speed flight.

The stability of the airplane in either the landing or high-speed configuration was decreased by an increase in the radius of gyration about the normal axis or by an inclination of the principal longitudinal axis downward at the nose. An increase in the radius of gyration about the longitudinal axis had a stabilizing effect in the high-speed configuration, but a destabilizing effect for landing.

With flaps and gear retracted, an increase in either the wing loading or altitude had small effects on the stability boundaries and on the period of the lateral oscillation but increased the time and number of cycles required for the oscillation to damp to half amplitude.

The calculations indicated instability of the basic airplane in the landing configuration. Some improvement in the characteristics near a lift coefficient of 1.0 seemed possible by reducing the flap deflection

[redacted]

or by extending the height of the vertical tail. At lift-coefficients of about 0.6 or less these changes appear to have little effect.

For the mass and aerodynamic parameters which were used in this investigation, the calculations indicated that the airplane would not meet the Bureau of Aeronautics criterion for satisfactory damping of the lateral oscillation in the landing configuration (flaps and gear down) and would meet the criterion in the high-speed configuration (flaps and gear up) only at lift coefficients greater than about 0.7.

INTRODUCTION

Recent studies (references 1 and 2) have indicated that the problem of the dynamic lateral stability of high-speed aircraft is extremely complex because of the large number of important variables. Therefore, it appears very difficult, if not impossible at the present time, to make charts such as those of reference 3 (which were for relatively low-speed, light aircraft with unswept wings) from which reliable estimates of the dynamic lateral stability characteristics of any high-speed aircraft can be made. For this reason it has been found expedient to investigate the dynamic lateral stability characteristics of specific high-speed airplane configurations. Many of the mass and aerodynamic parameters required for such investigations generally are not known to a high degree of accuracy; therefore, the quantitative reliability of the results, with respect to the airplane under consideration, may be questionable. When arbitrary variations are made to the various parameters, however, a reasonably reliable indication of the effects of possible modifications to the airplane or of changes in the flight attitude might be expected. The results also should be of use in indicating the degree of accuracy with which the aerodynamic and mass parameters must be determined in order to obtain accurate quantitative results.

This investigation is concerned with the dynamic lateral stability characteristics of the Douglas D-558-2 high-speed research airplane. (See fig. 1.) The mass characteristics used in the analysis were specified by the Douglas Aircraft Company, Inc. The aerodynamic parameters were obtained from wind-tunnel tests of a model of the D-558-2 airplane or, in some instances, from estimations based on tests of other models.

SYMBOLS AND COEFFICIENTS

The symbols and coefficients used herein are defined as follows:

h altitude, feet

α angle of attack of airplane reference axis (fig. 2), degrees

β angle of sideslip, radians

Λ angle of sweep, positive for sweepback, degrees

δ_f flap deflection, degrees

ρ mass density of air, slugs per cubic foot

b wing span, feet

S wing area, square feet

A wing aspect ratio $\left(\frac{b^2}{S}\right)$

l distance from center of gravity of airplane to center of pressure of vertical tail, feet

z perpendicular distance from fuselage center line to center of pressure of vertical tail, feet

W weight of airplane, pounds

m mass of airplane, slugs per cubic foot

μ relative density factor $\left(\frac{m}{\rho Sb}\right)$

η inclination of principal longitudinal axis of airplane with respect to flight path, positive when principal axis is above flight path at nose, degrees (fig. 2)

ϵ angle between fuselage center line (reference axis) and principal axis, positive when reference axis is above principal axis at nose of airplane (fig. 2), degrees

k_{X_0} radius of gyration about principal longitudinal axis, feet

k_{Z_0} radius of gyration about principal normal axis, feet

q dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

C_L trim lift coefficient $\left(\frac{W}{qS}\right)$

C_l rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qSb}\right)$

C_Y lateral-force coefficient $\left(\frac{\text{Lateral force}}{qS}\right)$

V airplane velocity, feet per second

r yawing angular velocity, radians per second

p rolling angular velocity, radians per second

M Mach number, $\left(\frac{V}{\text{Local speed of sound}}\right)$

$$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$$

$$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$$

$$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$$

$$C_{l_p} = \frac{\partial C_l}{\partial \frac{pb}{2V}}$$

$$C_{n_p} = \frac{\partial C_n}{\partial \frac{pb}{2V}}$$

$$C_{l_r} = \frac{\partial C_l}{\partial \frac{rb}{2V}}$$

$$C_{n_r} = \frac{\partial C_n}{\partial \frac{rb}{2V}}$$

$T_{1/2}$ time for oscillation to reduce to half amplitude, seconds

T_2 time for oscillation to double amplitude, seconds

$C_{1/2}$ number of cycles required for lateral oscillation to reduce to half amplitude

C_2 number of cycles required for lateral oscillation to double amplitude

P period of lateral oscillation, seconds

Subscript:

t vertical-tail contribution

SCOPE AND METHOD

The present investigation included the determination of the effects of various mass, aerodynamic, and dimensional parameters on the dynamic lateral stability characteristics of the Douglas D-558-2 airplane in the landing condition (flaps and gear extended) and in the high-speed condition (flaps and gear retracted). For the landing condition, the effects of wing loading, extension of the vertical tail, and reduction of the flap deflection from 50° to 30° were investigated. The effects on the dynamic lateral stability of varying the parameters C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η also were investigated for the landing and the high-speed conditions. In determining the effects of these parameters, C_{l_p}, C_{n_p}, and C_{n_r} were varied ± 50 percent; k_{X_0} and k_{Z_0} were varied ± 20 percent; and η was varied $\pm 2^\circ$. These variations were selected because they were believed to cover the maximum probable error in estimating the parameters involved. For the high-speed case, the effects of altitude and wing loading were investigated.

The speed range covered by the various conditions investigated was from about 135 miles per hour at sea level up to speeds corresponding to a Mach number of about 0.85.

All calculations in this investigation were made for level flight and were made by the use of the equations of reference 2. No corrections were made for power effects, which were believed to be small.

MASS AND AERODYNAMIC CHARACTERISTICS

The basic values of the mass characteristics of the airplane and the aerodynamic parameters are given in table I. The static-stability parameters C_{l_β} and C_{n_β} for the complete airplane, and the parameters C_{l_β}, C_{n_β}, C_{Y_β} with the vertical tail off were obtained from wind-tunnel tests of a model of the D-558-2 airplane. The rotary derivatives C_{l_r}, C_{n_r}, C_{l_p}, and C_{n_p} for the airplane with the vertical tail off were estimated with the aid of references 4 to 6. The vertical-tail contributions to the rotary derivatives were estimated by use of equations similar to those presented in reference 7. No corrections have been made to any of the derivatives to account for Mach number effects.

RESULTS AND DISCUSSION

Presentation of Results

The results of this investigation are presented as a series of figures of the neutral-oscillatory-stability boundary plotted as a function of C_{n_β} and C_{l_β}, and figures of the variations of period and rate of damping (cycles and seconds required for lateral oscillation to damp to half amplitude or double amplitude) with lift coefficient. The neutral-spiral-stability boundary was calculated for each condition investigated, but the boundaries are not presented since they were not appreciably shifted by any of the variations investigated and, in all instances, the airplane was spirally stable. The pertinent results obtained for the lateral oscillation and for the aperiodic modes (spiral and damping in roll) are summarized in table II for each condition investigated.

The results are divided into three groups. The first group is for the airplane with flaps and landing gear retracted and gives the results obtained for:

(a) the effects of altitude for a wing loading of 53 pounds per square foot (figs. 3 and 4)

(b) the effects of wing loading for flight at 20,000 feet altitude (figs. 5 and 6)

(c) the effects of varying the parameters C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η (fig. 7)

The second group of figures is for the airplane flying at sea level with flaps deflected 50° and landing gear lowered. In this group are shown:

(a) the effects of wing loading (figs. 8 and 9)

(b) the effects of varying C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η (fig. 10)

The third group of figures presents results obtained from assumed modifications to the airplane configuration for the landing condition. The results are presented for:

(a) the effects of reducing the flap deflection from 50° to 30° (figs. 11 and 12)

(b) the effect of increasing the vertical-tail height by 14 inches (figs. 13 and 14)

The damping characteristics of several of the airplane configurations investigated are compared in figure 15 with the present Bureau of Aeronautics specifications for satisfactory damping of the lateral oscillation.

Airplane with Flaps and Gear Retracted

Basic condition.- The calculated dynamic lateral stability characteristics of the airplane flying at sea level with a wing loading of 53 pounds per square foot are shown by the solid curves of figures 3 and 4. This condition is for the airplane with only about 1800 pounds of fuel remaining and is used as a basis for comparing the stability as various parameters and conditions are changed. The calculations indicate that the airplane is laterally stable throughout the lift-coefficient range, but that the stability decreases as the lift coefficient decreases from 0.8 to about 0.35 (fig. 4) and then increases again as the lift coefficient is made smaller. One fairly common criterion for satisfactory dynamic lateral stability characteristics is that the lateral oscillation must damp to half amplitude within two cycles - that is, $C_{1/2}$ must be less than 2. For the case under discussion the calculations indicate that the airplane meets this requirement only at lift coefficients below 0.2 and above 0.5, although the number of cycles required to damp to half amplitude did not greatly exceed the requirement at any of the lift coefficients investigated.

The present Bureau of Aeronautics specifications for flying qualities of piloted aircraft (reference 8) state that the damping of the lateral oscillation shall be positive and shall be such that the time to damp to half amplitude and the period shall fall within the satisfactory area of the chart presented as the lower part of figure 15. The chart as given in reference 8 can be used only for stable airplanes. However, for completeness, an addition can be made to the chart, as was done in figure 15 of this paper, to permit plotting of points representing unstable configurations. The region between the two charts of figure 15 is a region for which at least 20 seconds are required for the lateral oscillation to double amplitude or to reduce to half amplitude, and for practical cases, this can be considered as a region of approximate neutral oscillatory stability.

For the case under discussion the use of figures 4 and 15 indicates that the airplane meets the Bureau of Aeronautics criterion only for lift coefficients greater than about 0.7.

Effects of altitude.- An increase in altitude caused a destabilizing shift of the neutral-oscillatory-stability boundary, and the shift generally increased as the lift coefficient was made smaller (fig. 3). The destabilizing shift was not important at high lift coefficients as indicated by figure 4. At low lift coefficients, however, increase in altitude became important because of the smaller margin of stability of the airplane. The time required for a lateral oscillation to damp to half amplitude increased with increase in altitude, and the increase generally became greater as the lift-coefficient was made smaller. Altitude had no appreciable effect on the period but did affect $C_{1/2}$ since

$$C_{1/2} = \frac{T_{1/2}}{P}$$

A study of figures 3 and 4 indicates that the point representing the airplane on the chart of C_{n_β} against C_{l_β} gives a qualitative indication of the airplane stability by its location with respect to the boundary - that is, if the point falls on the stable side of the boundary, the airplane is laterally stable as indicated by $T_{1/2}$. However, the location of the point relative to the boundary generally gives little or no quantitative indication of the airplane stability, especially if the point is near the boundary. For example, the points on figures 3(a) and 3(b) are approximately the same distance from their respective boundaries, but the time required for the oscillation to damp to half amplitude is about 10 seconds for the case of figure 3(a) and about 30.2 seconds for the case of figure 3(b) (for 20,000 ft altitude).

Effect of wing loading.- The calculations indicate that an increase in wing loading caused a small decrease of the stable region throughout the lift-coefficient range (fig. 5). The effect was similar to that observed for an increase in altitude, which follows from the fact that wing loading and altitude enter into the stability equations, at a given lift coefficient, only through the relative-density factor μ. It is to be noted that for a wing loading of 68.2 (corresponding to the airplane with about 3300 lb of fuel) the time required for the lateral oscillation to decrease to half amplitude increases very rapidly in going from $C_L = 0.1$ to $C_L = 0.2$ and from $C_L = 0.5$ to $C_L = 0.4$ (fig. 6). Calculations made for $C_L = 0.2$ indicated oscillatory instability. These calculations indicate that the conditions likely to be the more undesirable as far as actual flight is concerned (for constant altitude) are those for which the airplane is heavily loaded (large fuel load). It appears that serious instability might occur at high speeds and high altitude if the airplane still carries a fairly large amount of fuel.

Effects of variations of aerodynamic and mass parameters.- The calculated effects on the neutral-oscillatory-stability boundary of varying the parameters C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η are shown in figure 7 for a wing loading of 68.2 pounds per square foot and a Mach number of 0.85 at 20,000 feet altitude. The variations were selected arbitrarily to indicate effects of possible errors in the estimation of the derivatives. Variations of C_{l_p} by ±50 percent had little effect on the oscillatory-stability boundary (fig. 7(a)) for values of C_{l_β} less negative than -0.10. For values of C_{l_β} more negative than -0.10 decreasing C_{l_p} caused a stabilizing shift of the boundary. Other unpublished dynamic-lateral-stability calculations made for high-speed airplanes have shown similar trends for some airplane configurations. An inspection of figure 7 shows that the stable range was increased by the following variations of the parameters: An increase in the absolute magnitude of C_{n_p} or C_{n_r} (for this condition C_{n_p} was always positive and C_{n_r} always negative for the values of C_{n_β} and C_{l_β} shown in fig. 7); an increase of k_{x_0} or a decrease of k_{z_0}. The stable range also was increased by making η more positive. It should be noted that during these calculations each parameter was varied separately. The effects to be expected from the simultaneous variation of two or more parameters generally are not equal to the sum of the individual effects. The changes noted in the boundaries apply only to the conditions for which the calculations were made. At some other lift coefficient, wing loading, or altitude the effects caused by variations of the parameters probably would be different in magnitude and might be different even in direction. The results of figure 7 indicate that even small errors in the estimation of certain derivatives can cause appreciable quantitative errors in the calculated stability characteristics.

Airplane at Sea Level with Flaps Deflected 50°

and Landing Gear Lowered

Basic condition.- The calculated lateral-stability boundaries and damping characteristics of the D-558-2 airplane with a wing loading of 53 pounds per square foot are shown as the solid curves of figures 8 and 9 and are used as a basis for noting changes in the stability and damping as various parameters are modified. The results of the calculations (figs. 8 and 9) indicate that the airplane in the basic condition is laterally unstable throughout the lift-coefficient range and that the instability becomes worse as the lift coefficient is decreased. The dynamic lateral stability characteristics are unsatisfactory for this condition. As noted previously, small errors in estimating some of the stability derivatives or mass characteristics might cause misleading quantitative results; hence, definite conclusions regarding the characteristics of the actual airplane cannot be made on the basis of the results presented herein. The effects of varying some of the parameters should give reliable trends.

Effect of wing loading.- The results of the calculations indicate that an increase in wing loading caused a decrease of the stable region (fig. 8). In this case the boundary shift decreased as the lift coefficient was made smaller, which is a reversal of the effect noted for the airplane with flaps and gear retracted (fig. 5). Wing loading had no appreciable effect on the period but decreased the time required for the lateral oscillation to double amplitude (fig. 9). The wing loadings investigated were 45.5, 53.0, and 78.4 pounds per square foot which correspond roughly to landing with most of the fuel gone, landing with a fuel reserve of about 1800 pounds, and landing (or take-off) with a full fuel load. The calculations indicate that the worst condition likely to be encountered with flaps and gear down is the take-off with a full fuel load.

Effects of variations of aerodynamic and mass parameters.- The calculated effects of varying C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η are shown in figure 10 for a wing loading of 45.5 pounds per square foot and a lift coefficient of 1.0. The results of the calculations indicate that variation of C_{n_p} by ±50 percent had no appreciable effect on the boundary and that the stable region was increased by increasing the absolute magnitude of C_{l_p} or C_{n_r} (for this configuration, C_{l_p} and C_{n_r} were always negative), by decreasing k_{X_0} or k_{Z_0}, or by making η more positive. It should be noted that for these calculations the variables were changed one at a time. The large effect on the boundary of varying such parameters as C_{l_p}, k_{X_0}, k_{Z_0}, or η indicates that if the characteristics used herein had been only a few percent different from the values used, the results of the stability calculations might be considerably different. These calculations indicate the need for accurate determination (experimental or theoretical) of the mass and aerodynamic parameters of any airplane for which dynamic-lateral-stability calculations are to be made, if the results of the calculations are to be accepted with any degree of certainty.

A comparison of figures 7 and 10 indicates that only variations of C_{n_r}, C_{n_p}, k_{Z_0}, and η produce consistent changes in the boundary for a given change in the parameter for the cases investigated (landing and high speed).

Effects of Assumed Modifications to Airplane

Effect of reducing flap deflection.- Results of calculations (figs. 8 and 9) have indicated that the D-558-2 airplane is laterally unstable for the condition of flaps and gear lowered. Calculations have indicated that for this particular configuration the stability would be improved (at least at $C_L = 1.0$) by increasing the absolute values of C_{l_p} or C_{n_r}, by decreasing k_{X_0} or k_{Z_0}, or by making η more positive (fig. 10).

Of these parameters, probably the one easiest to change is the principal axis inclination η. The data of table I indicate that a flap deflection of 50° produces an increment of lift equal to that produced by a 5° change in angle of attack. If the flap deflection were to be reduced to 30°, then for constant lift it would be necessary to increase α (and hence η) by about 2°. Such a change in η was shown to be very beneficial at least at $C_L = 1.0$ (fig. 10). It should be noted, however, that a reduction in flap deflection produces changes in some of the aerodynamic derivatives as well as in η; hence, the over-all effect on the dynamic stability can be evaluated only by calculations taking into account the changes in all of the derivatives.

The results obtained for the dynamic lateral stability characteristics of the airplane with the flaps deflected 30° are shown in figures 11 and 12. Also shown in the figures are the characteristics of the airplane with flaps deflected 50°. The results indicate that at $C_L = 1.0$ a large stabilizing shift of the boundary was obtained by reducing the flap deflection to 30° but that the shift became smaller as the lift coefficient was decreased. It is also noted that the point representing the airplane on the plane of $C_{n_{\beta}}$ against $C_{l_{\beta}}$ moved in the same direction as the boundary; therefore, the increase in stability was not very great (fig. 12). At a lift coefficient of 1.0 the calculations indicated that the airplane was stable but about 6.7 cycles were required for the lateral oscillation to damp to half amplitude, and the condition, therefore, was not very satisfactory. At lower lift coefficients the airplane remained unstable. Thus, it appears that a reduction in flap deflection cannot be expected to cause any appreciable increase in stability at moderate or small lift coefficients.

Effect of increasing the vertical-tail height.- One method of securing dynamic lateral stability is to make $C_{n_{\beta}}$ large enough so that the point representing the airplane on the chart of $C_{n_{\beta}}$ against $C_{l_{\beta}}$ is well above the oscillatory-stability boundary. The value of $C_{n_{\beta}}$ can be increased easily by increasing the vertical-tail height. The effectiveness of this solution depends on how the increased tail height affects all the derivatives. Computations of the dynamic lateral stability characteristics of the airplane were made for an assumed vertical-tail extension of 14 inches for the condition of sea-level flight with flaps deflected 50°. The results of the computations are compared in figures 13 and 14 with the results for the airplane with its original vertical tail. It is clear that increasing the vertical-tail height caused a small stabilizing shift of the stability boundary throughout most of the lift-coefficient range (fig. 13). At high lift coefficients the calculated increase in $C_{n_{\beta}}$ caused by the tail addition was enough to place the point representing the airplane on the stable side of the stability boundary. The calculated effect of the tail extension on $C_{l_{\beta}}$ was small at high lift coefficients. As the lift coefficient was decreased, however, the calculated increase in $C_{n_{\beta}}$ became smaller, and C_{l_β} became more negative. The net result was that as the lift coefficient decreased the effectiveness of the vertical tail in improving the stability was decreased. This is also indicated in figure 14. Thus, although some improvement in the dynamic stability characteristics at $C_L = 1.0$ might be expected from an extension of the vertical tail, it appears that little, if any, improvement would be obtained at lift coefficients of about 0.6 or less.

CONCLUSIONS

Calculations have been made to determine the effects of various mass, aerodynamic, and dimensional parameters on the dynamic lateral stability of the Douglas D-558-2 airplane. The results of the investigation have led to the following conclusions:

1. Accurate determination of the stability derivatives, the radii of gyration, and the inclination of the principal axes are required if calculations of the dynamic lateral stability are expected to be of quantitative significance.

2. The dynamic stability was improved in the landing and high-speed configurations by an increase in the magnitude of the damping in yaw, by an increase in the magnitude of the yawing moment due to rolling (in the positive direction), by making the inclination of the principal axes more positive, or by decreasing the magnitude of the radius of gyration about the principal normal axis.

3. An increase in the damping in roll had a large stabilizing effect in the landing configuration but had a small irregular effect in high-speed flight.

4. An increase in the radius of gyration about the principal longitudinal axis improved the stability in high-speed flight but was destabilizing in the landing attitude.

5. With flaps and gear retracted an increase in either the wing loading or the altitude had rather small effects on the stability boundaries and on the period of the lateral oscillation but increased the time and number of cycles required for the oscillation to damp to half amplitude.

6. The calculations indicated dynamic lateral instability of the basic airplane configuration in the landing attitude. Some improvements in stability near a lift coefficient of 1.0 seemed possible by reducing the flap deflection or by extending the height of the vertical tail. At lift coefficients of about 0.6 or less, these changes appear to have little effect.

7. For the configurations investigated, the calculations indicated that the airplane would not meet the Bureau of Aeronautics criterion for satisfactory damping of the lateral oscillation in the landing configuration (flaps and gear down), and would meet the criterion in the high-speed configuration (flaps and gear up) only at lift coefficients greater than about 0.7.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCES

1. Sternfield, Leonard: Effect of Product of Inertia on Lateral Stability. NACA TN No. 1193, 1947.

2. Sternfield, Leonard: Some Considerations of the Lateral Stability of High-Speed Aircraft. NACA TN No. 1282, 1947.

3. Zimmerman, Charles H.: An Analysis of Lateral Stability in Power-Off Flight with Charts for Use in Design. NACA Rep. No. 589, 1937.

4. Toll, Thomas A., and Queijo, M. J.: Approximate Relations and Charts for Low-Speed Stability Derivatives of Swept Wings. NACA TN No. 1581, 1948.

5. Lichtenstein, Jacob H.: Effect of High-Lift Devices on the Low-Speed Static Lateral and Yawing Stability Characteristics of an Untapered 45° Sweptback Wing. NACA RM No. L8G20, 1948.

6. Queijo, M. J., and Lichtenstein, Jacob H.: The Effects of High-Lift Devices on the Low-Speed Stability Characteristics of a Tapered 37.5° Sweptback Wing of Aspect Ratio 3 in Straight and Rolling Flow. NACA RM No. L8I03, 1948.

7. Bamber, Millard J.: Effect of Some Present-Day Airplane Design Trends on Requirements for Lateral Stability. NACA TN No. 814, 1941.

8. Anon.: Specification for Flying Qualities of Piloted Airplanes. NAVAER SR-119B, Bur. Aero., June 1, 1948.

[redacted]

TABLE I

BASIC STABILITY DERIVATIVES AND MASS CHARACTERISTICS OF THE D-558-2 AIRPLANE

Condition	Flaps and gear up						Gear down $\delta_f = 50^\circ$				Gear down $\delta_f = 30^\circ$				Gear down $\delta_f = 50^\circ$ vertical tail extended 14 in.			
C_L	0.10	0.138	0.20	0.40	0.60	0.80	0.4	0.6	0.8	1.0	0.4	0.6	0.8	1.0	0.4	0.6	0.8	1.0
α	-.30°	.24°	1.10°	4.10°	7.10°	10.10°	-1.30°	2.10°	5.25°	8.40°	1.10°	4.20°	7.25°	10.40°	-1.30°	2.10°	5.25°	8.40°
η	-3.65°	-3.11°	-2.25°	.75°	3.75°	6.75°	-6.65°	-3.25°	-.10°	3.05°	-4.25°	-1.15°	1.90°	5.05°	-6.25°	-3.25°	-0.10°	3.05°
C_{Y_β} (tail off)	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057	-.057
C_{l_β}	-.030	-----	-.057	-.120	-.193	-.267	-.076	-.109	-.151	-.192	-.096	-.144	-.199	-.255	-.076	-.109	-.151	-.192
C_{n_β}	-.174	-.172	-.172	-.155	-.128	-.090	-.183	-.168	-.149	-.127	-.172	-.155	-.129	-.102	-.183	-.168	-.149	-.127
C_{l_p}	-.270	-.270	-.272	-.277	-.282	-.295	-.276	-.280	-.280	-.280	-.275	-.280	-.285	-.286	-.276	-.280	-.280	-.280
C_{n_p}	-.007	-.010	-.012	-.023	-.033	-.045	-.020	-.034	-.045	-.058	-.021	-.033	-.045	-.056	-.020	-.034	-.045	-.058
C_{l_r}	.030	.042	.062	.123	.180	.240	.170	.235	.296	.360	.150	.213	.275	.337	.170	.235	.296	.360
C_{n_r}	-.030	-.032	-.030	-.030	-.030	-.040	-.066	-.071	-.082	-.100	-.051	-.055	-.064	-.084	-.066	-.071	-.082	-.100
C_{Y_β} (tail on)	-.430	-----	-.421	-.397	-.361	-.319	-.448	-.455	-.451	-.436	-.427	-.420	-.400	-.373	-.500	-.508	-.503	-.486
C_{l_β}	-.084	-----	-.103	-.149	-.206	-.268	-.138	-.154	-.178	-.202	-.142	-.174	-.213	-.255	-.165	-.170	-.188	-.205
C_{n_β}	.116	-----	.112	.109	.109	.109	.122	.142	.158	.166	.116	.127	.138	.142	.151	.192	.206	.215
C_{l_p}	-.287	-----	-.281	-.280	-.283	-.295	-.295	-.290	-.284	-.281	-.287	-.285	-.285	-.286	-.303	-.295	-.287	-.282
C_{n_p}	.076	-----	.060	.024	-.012	-.044	.076	.036	-.003	-.042	.051	.014	-.023	-.056	.103	.060	.017	-.028
C_{l_r}	.113	-----	.131	.164	.201	.242	.266	.305	.338	.376	.222	.260	.297	.337	.293	.329	.358	.390
C_{n_r}	-.479	-----	-.468	-.439	-.396	-.356	-.536	-.550	-.556	-.556	-.491	-.491	-.477	-.464	-.629	-.644	-.648	-.644
$C_{Y_{\beta_t}}$	-.373	-----	-.364	-.340	-.304	-.262	-.391	-.398	-.394	-.379	-.370	-.363	-.343	-.316	-.443	-.451	-.446	-.429
l	19.4						19.4				19.4				19.9			
z	3.50						3.50				3.50				4.00			
ϵ	-3.35°						-5.35°				-5.35°				-5.35°			
k_{X_0}	3.12						3.12				3.12				3.12			
k_{Z_0}	9.86						9.86				9.86				9.86			

NACA

[redacted]

[redacted]

TABLE II

CALCULATED PERIOD AND DAMPING CHARACTERISTICS OF THE D-558-2 AIRPLANE

Configuration	C_L	C_{n_β}	C_{l_β}	W/S	h	δ_f	Lateral oscillation P	Lateral oscillation $T_{1/2}$	Lateral oscillation T_2	Spiral mode $T_{1/2}$	Damping-in-roll mode $T_{1/2}$
Flaps and gear up	0.1	0.116	-0.084	53	0	0	2.25	3.41	-----	9.35	0.20
↓	.2	.112	-.103	↓	↓	↓	3.08	6.38	-----	6.55	.29
↓	.4	.109	-.149	↓	↓	↓	3.63	8.89	-----	6.79	.37
↓	.6	.109	-.206	↓	↓	↓	3.51	6.05	-----	7.77	.46
↓	.8	.109	-.268	↓	↓	↓	3.17	3.62	-----	15.37	.14
Flaps and gear up	.1	.116	-.084	53	10,500	0	2.27	5.39	-----	10.94	.23
↓	.2	.112	-.103	↓	↓	↓	3.10	11.43	-----	7.73	.34
↓	.4	.109	-.149	↓	↓	↓	3.67	13.46	-----	7.94	.44
↓	.6	.109	-.206	↓	↓	↓	3.49	7.16	-----	9.12	.54
↓	.8	.109	-.268	↓	↓	↓	3.15	4.08	-----	18.01	.17
Flaps and gear up	.1	.116	-.084	53	20,000	0	2.31	10.05	-----	21.04	.19
↓	.2	.112	-.103	↓	↓	↓	3.15	30.32	-----	12.81	.27
↓	.4	.109	-.149	↓	↓	↓	3.70	21.97	-----	9.04	.39
↓	.6	.109	-.206	↓	↓	↓	3.49	8.48	-----	9.27	.51
↓	.8	.109	-.268	↓	↓	↓	3.13	4.61	-----	10.66	.64
Flaps and gear up	.1	.116	-.084	68.2	20,000	0	2.32	22.94	-----	23.78	.21
↓	.2	.112	-.103	↓	↓	↓	3.18	-----	427.5	14.62	.30
↓	.4	.109	-.149	↓	↓	↓	3.71	39.53	-----	10.23	.44
↓	.6	.109	-.206	↓	↓	↓	3.49	9.67	-----	10.49	.58
↓	.8	.109	-.268	↓	↓	↓	3.12	5.11	-----	10.05	.73

NACA

[redacted]

[redacted]

TABLE II.- Concluded.

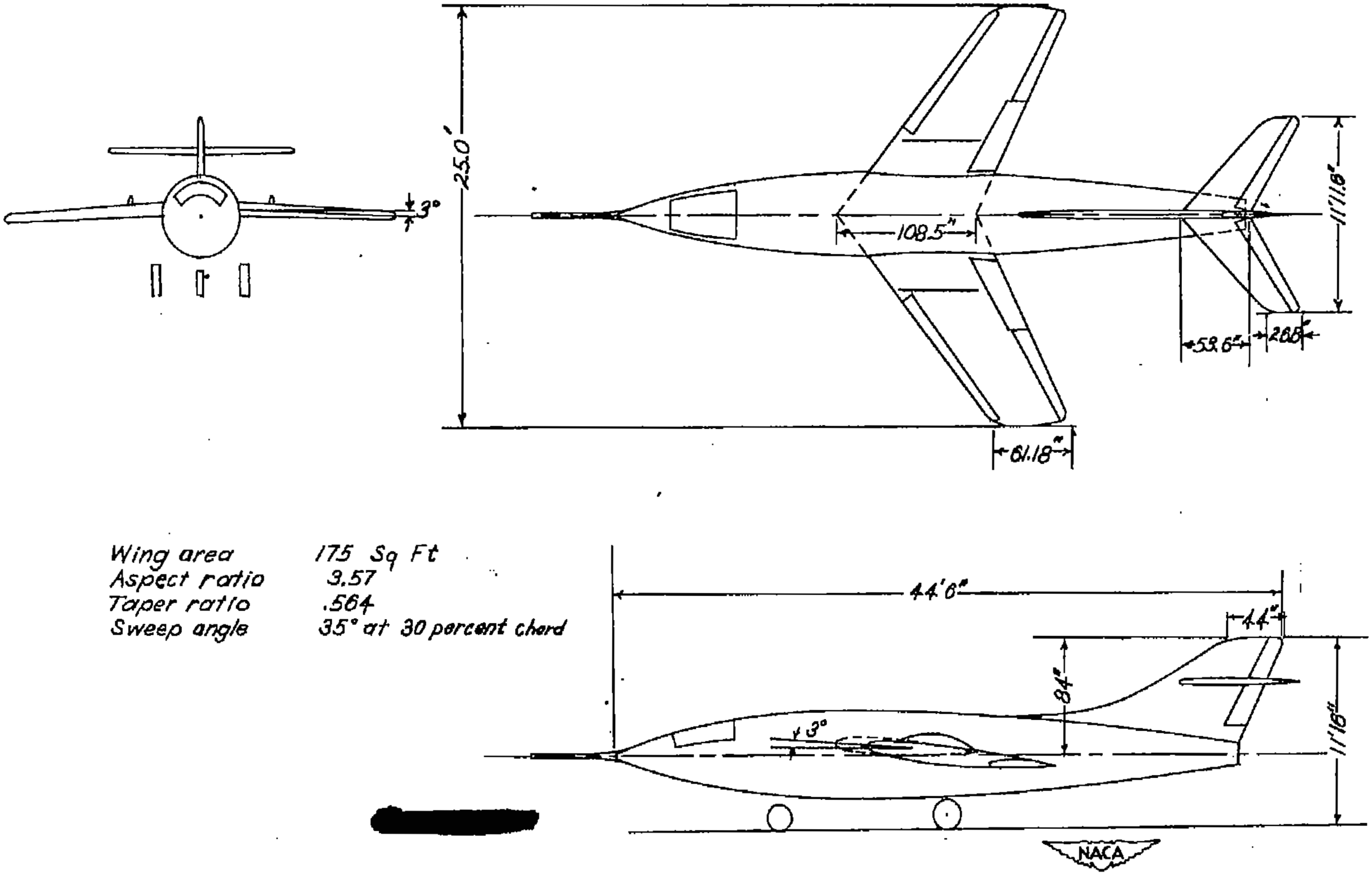
CALCULATED PERIOD AND DAMPING CHARACTERISTICS OF THE D-558-2 AIRPLANE

Configuration	C_L	C_{n_β}	C_{l_β}	W/S	h	δ_f	Lateral oscillation			Spiral mode $T_{1/2}$	Damping-in-roll mode $T_{1/2}$
							P	$T_{1/2}$	T_2		
Flaps and gear down	0.4	0.122	-0.138	53	0	50°	4.21	-----	2.88	6.95	0.23
↓	.6	.142	-.154	↓	↓	↓	4.20	-----	4.69	8.77	.29
↓	.8	.158	-.178	↓	↓	↓	4.00	-----	9.14	9.69	.34
↓	1.0	.166	-.202	↓	↓	↓	3.82	-----	69.57	10.56	.40
Flaps and gear down	.4	.122	-.138	78.4	0	50°	4.46	-----	2.39	8.56	.27
↓	.6	.142	-.154	↓	↓	↓	4.33	-----	3.73	10.63	.33
↓	.8	.158	-.178	↓	↓	↓	4.13	-----	6.27	11.81	.39
↓	1.0	.166	-.202	↓	↓	↓	3.89	-----	21.18	12.87	.47
Flaps and gear down, vertical tail extended 14 inches	.4	.151	-.165	53	0	50°	3.98	-----	2.88	5.56	.23
↓	.6	.192	-.170	↓	↓	↓	3.80	-----	6.98	9.47	.29
↓	.8	.206	-.188	↓	↓	↓	3.72	-----	25.96	10.52	.35
↓	1.0	.215	-.205	↓	↓	↓	3.61	19.08	-----	12.15	.40
Flaps and gear down	.4	.116	-.142	53	0	30°	4.05	-----	3.76	6.67	.24
↓	.6	.127	-.174	↓	↓	↓	4.06	-----	5.70	7.20	.30
↓	.8	.138	-.213	↓	↓	↓	3.79	-----	12.80	7.89	.35
↓	1.0	.143	-.255	↓	↓	↓	3.51	23.58	-----	8.50	.42

NACA

[redacted]

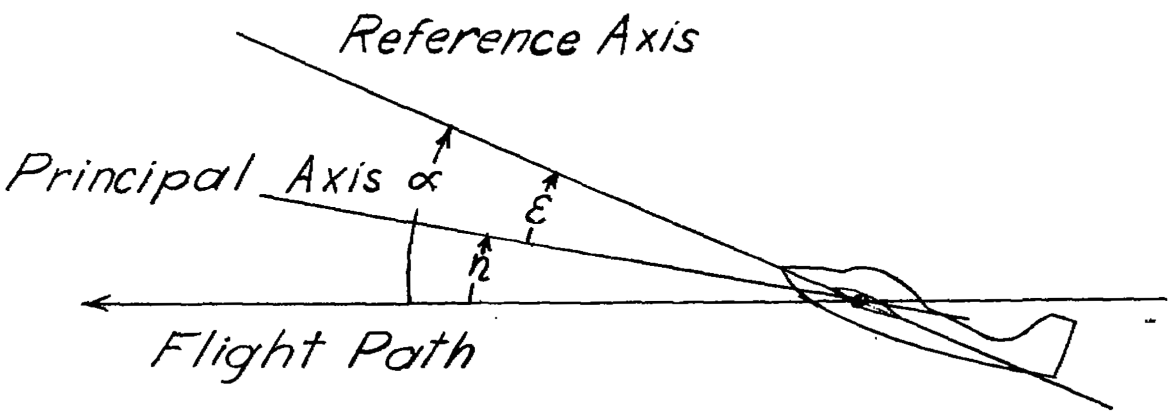
[redacted]



[redacted]

Figure 1.– Drawing of Douglas D-558-2 high-speed research airplane.

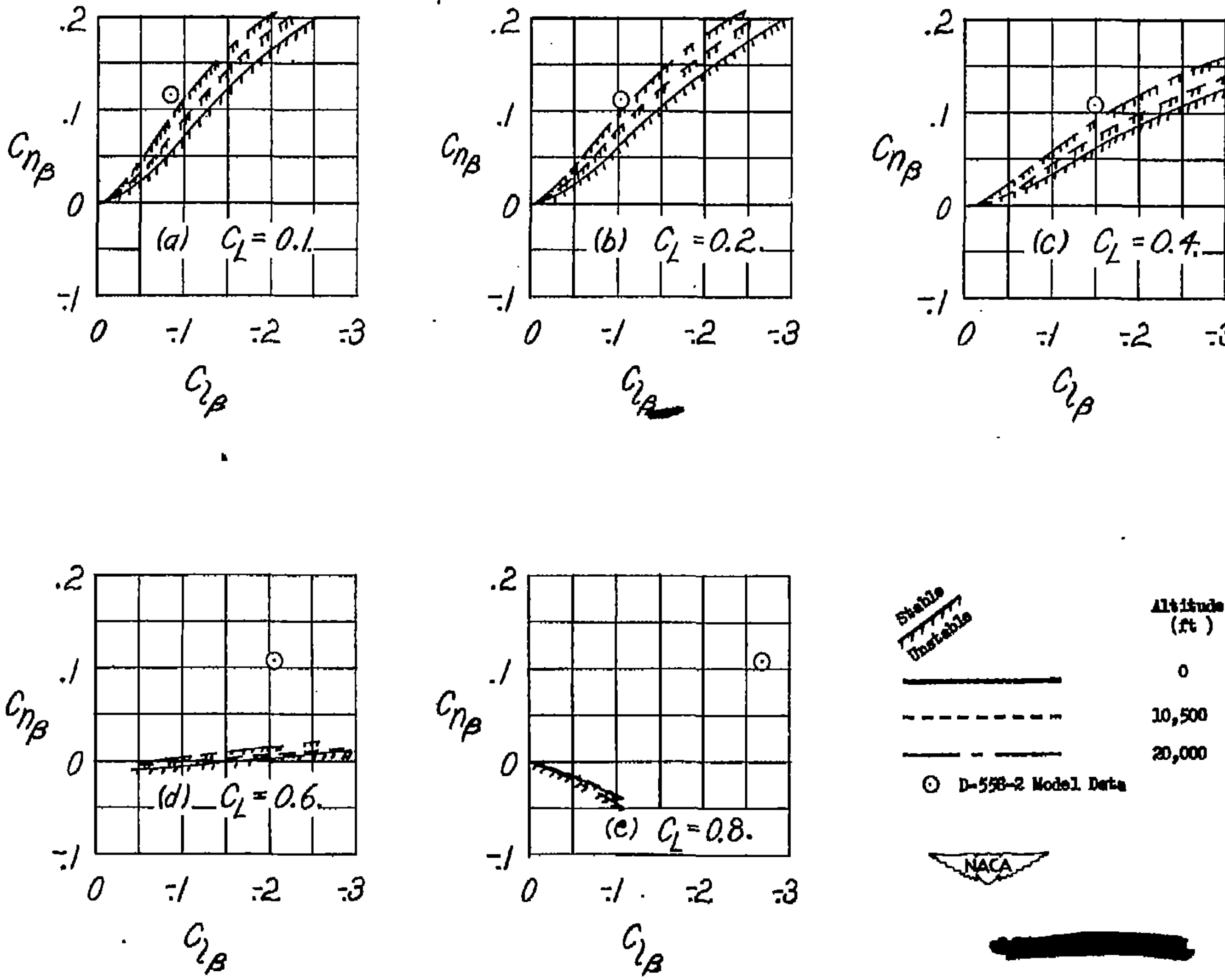
[redacted]



[redacted]

Figure 2.– Angular relationships in flight. Arrows indicate positive direction of angles. $\eta = \alpha - \epsilon$.

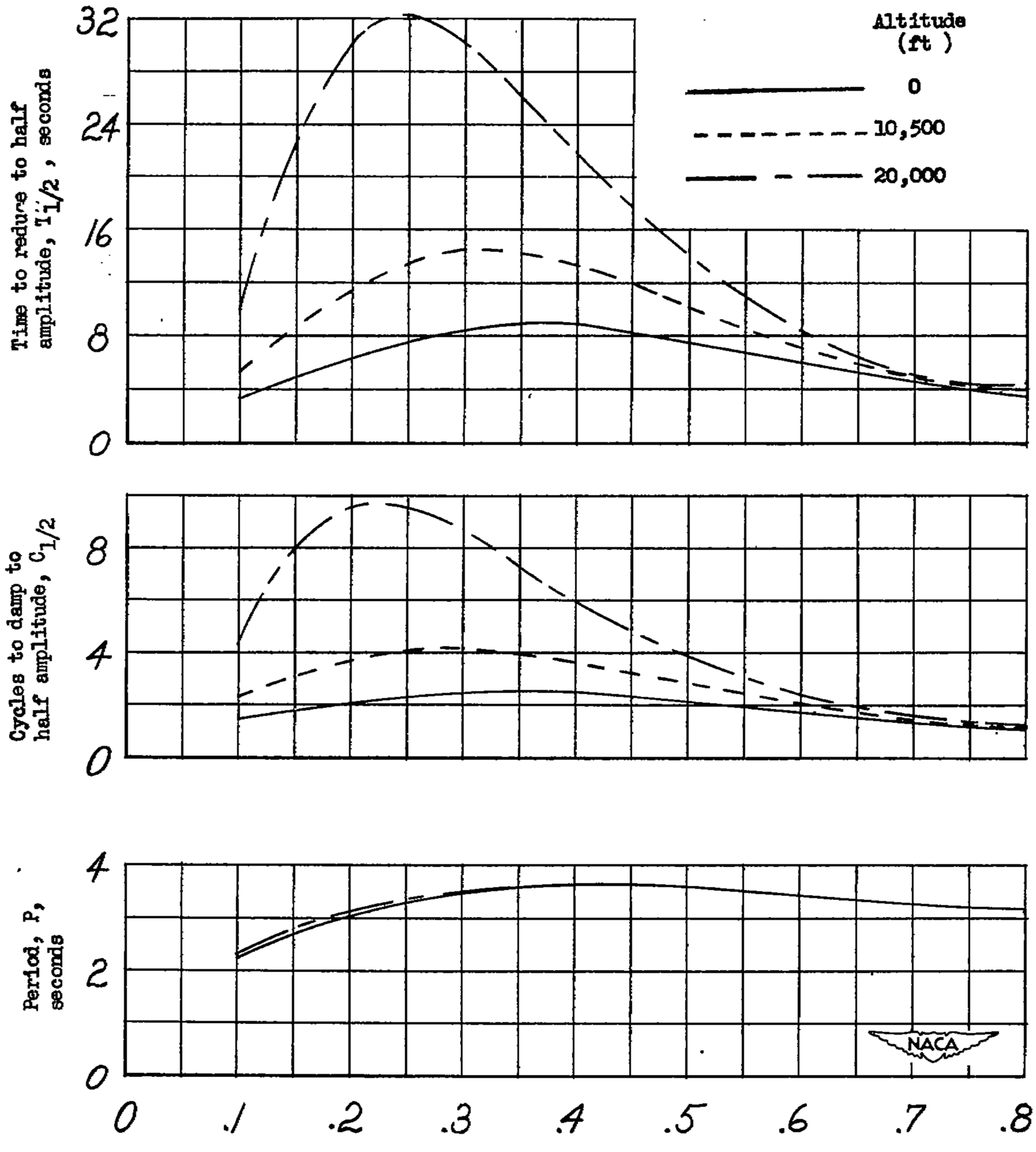
[redacted]



[redacted]

Figure 3.- Effect of altitude on the oscillatory-stability boundary. $\frac{W}{S} = 53$; flaps and gear retracted.

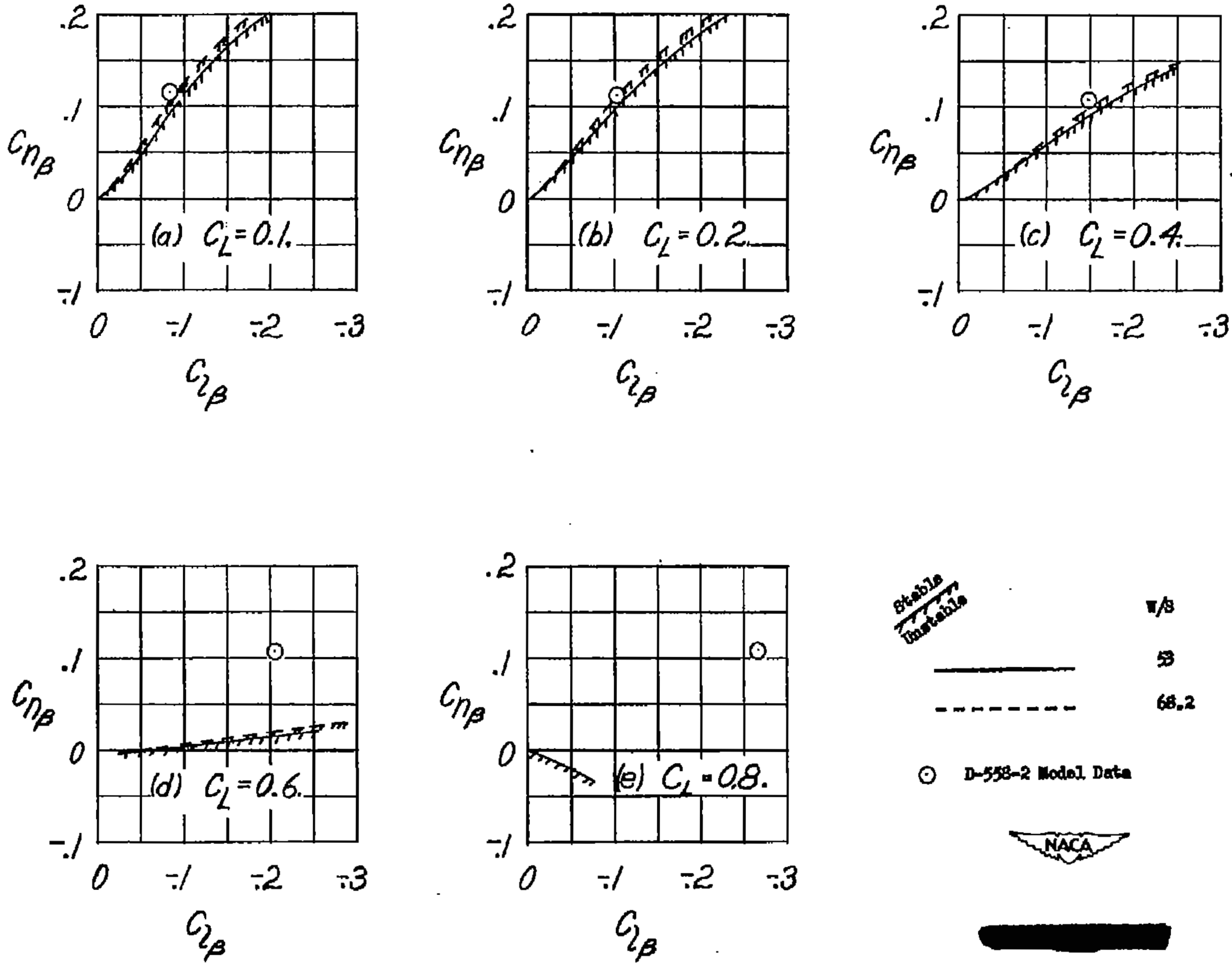
[redacted]



[redacted]

Figure 4.– Effect of altitude on the period and damping of the lateral oscillation. $\frac{W}{S} = 53$; flaps and gear retracted.

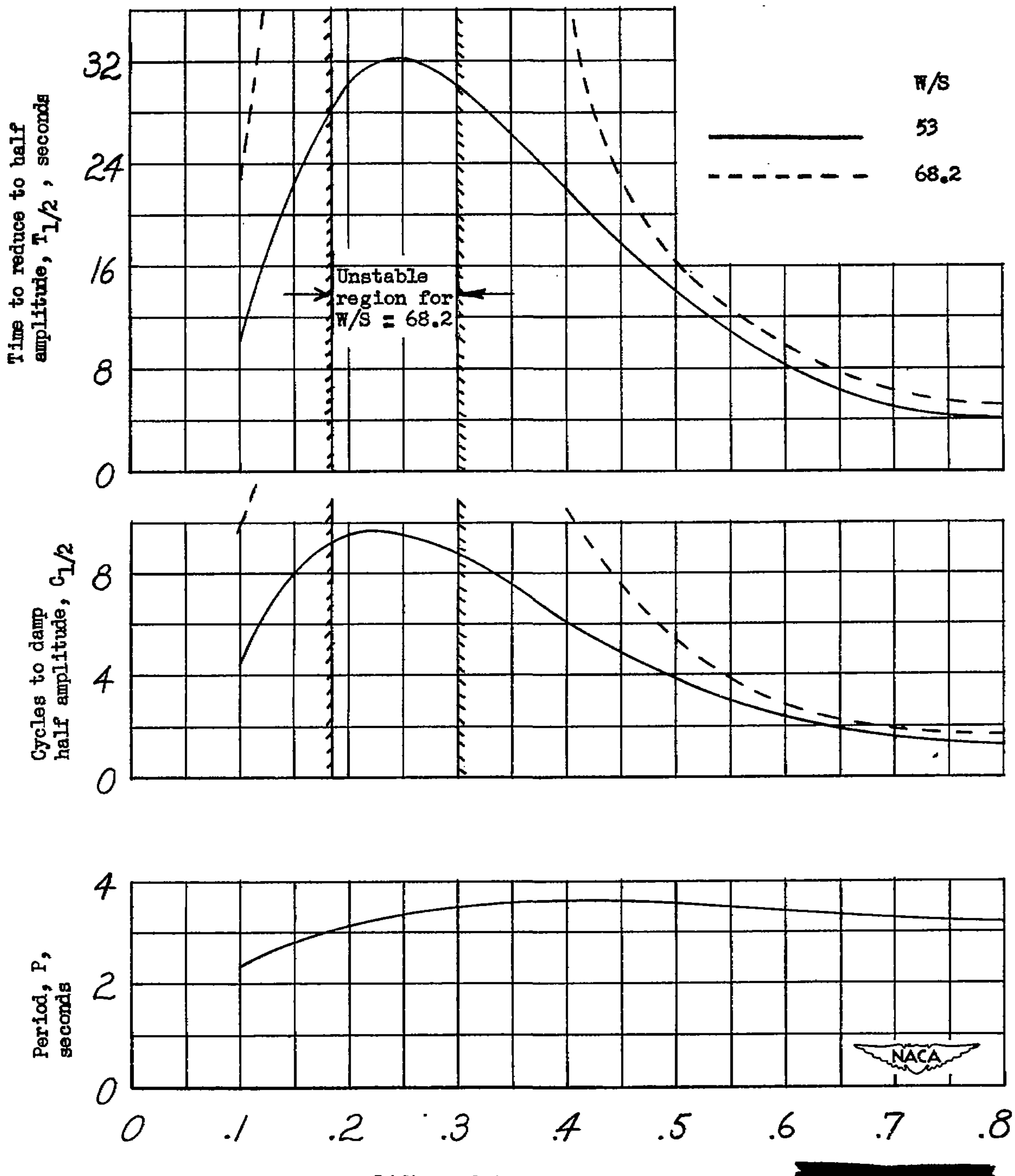
[redacted]



[redacted]

Figure 5.– Effect of wing loading on the oscillatory-stability boundary. h = 20,000 feet; flaps and gear retracted.

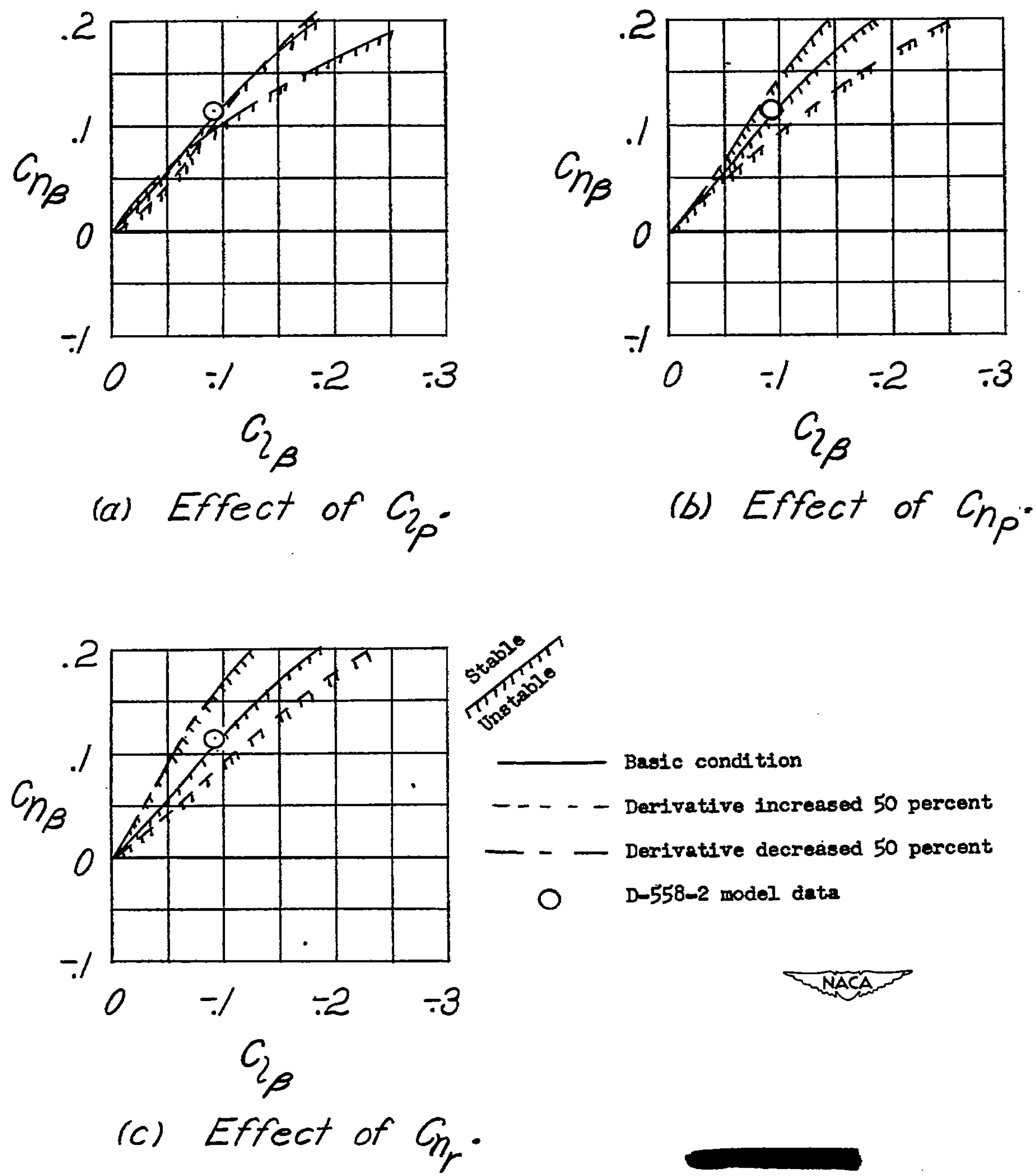
[redacted]



[redacted]

Figure 6.– Effects of wing loading on the period and damping of the lateral oscillation. h = 20,000 feet; flaps and gear retracted.

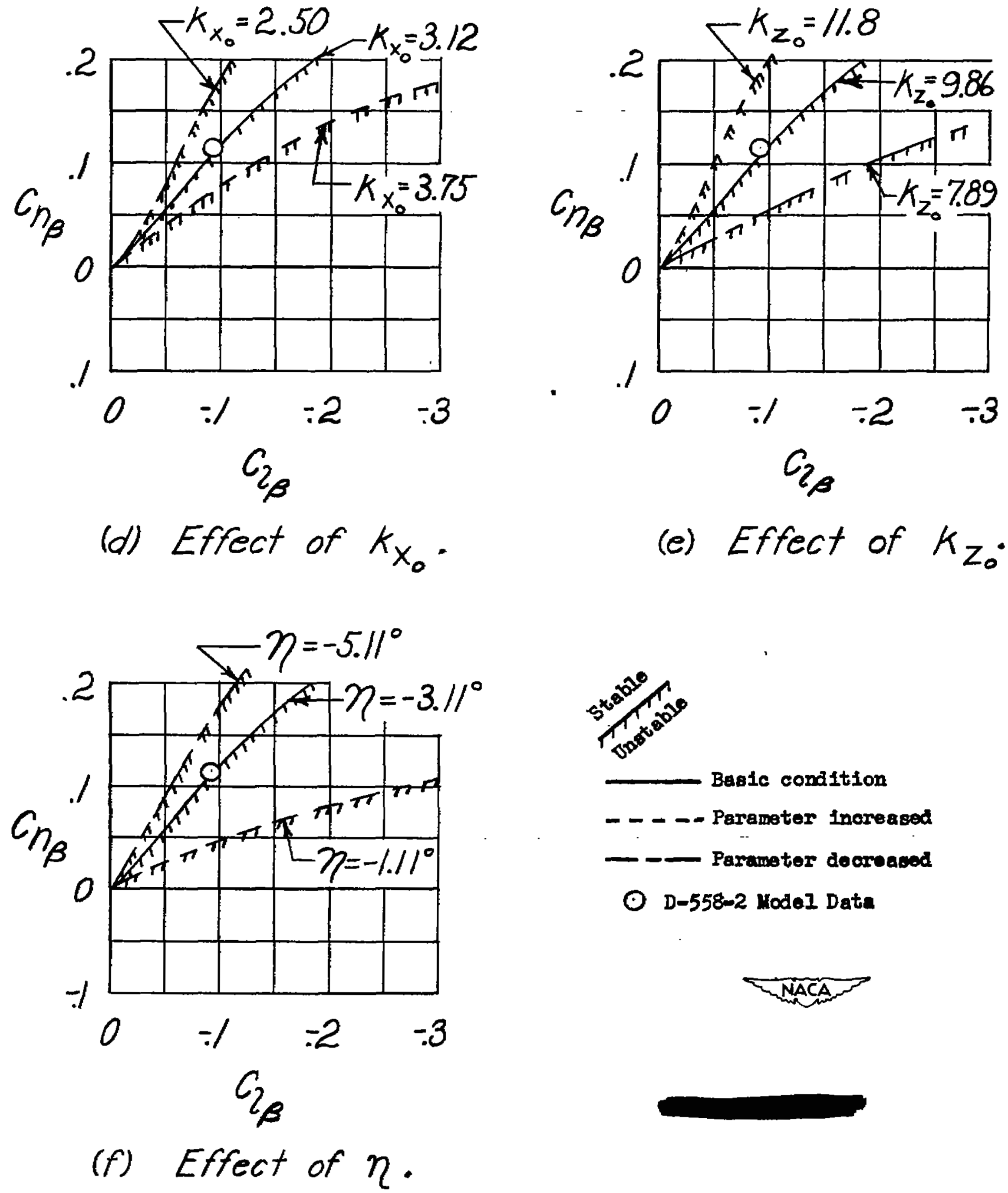
[redacted]



[redacted]

Figure 7.– Effects of variations of C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η on the oscillatory-stability boundary. $\frac{W}{S} = 68.2$; h = 20,000 feet; M = 0.85; flaps and gear retracted; $C_L = 0.138$.

[redacted]



(d) Effect of k_{x_o}.

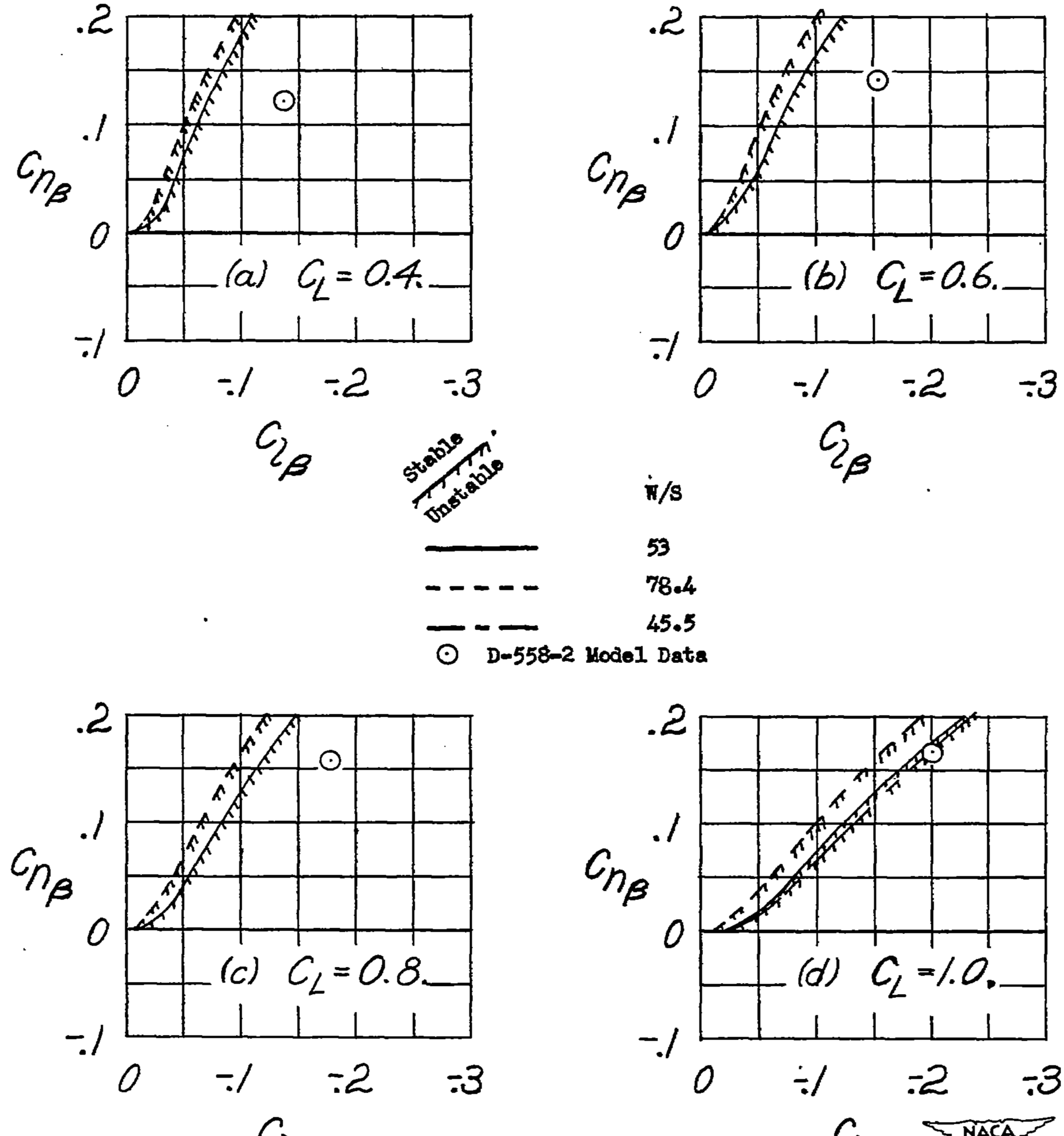
(e) Effect of k_{z_o}.

(f) Effect of η.

[redacted]

Figure 7.– Concluded.

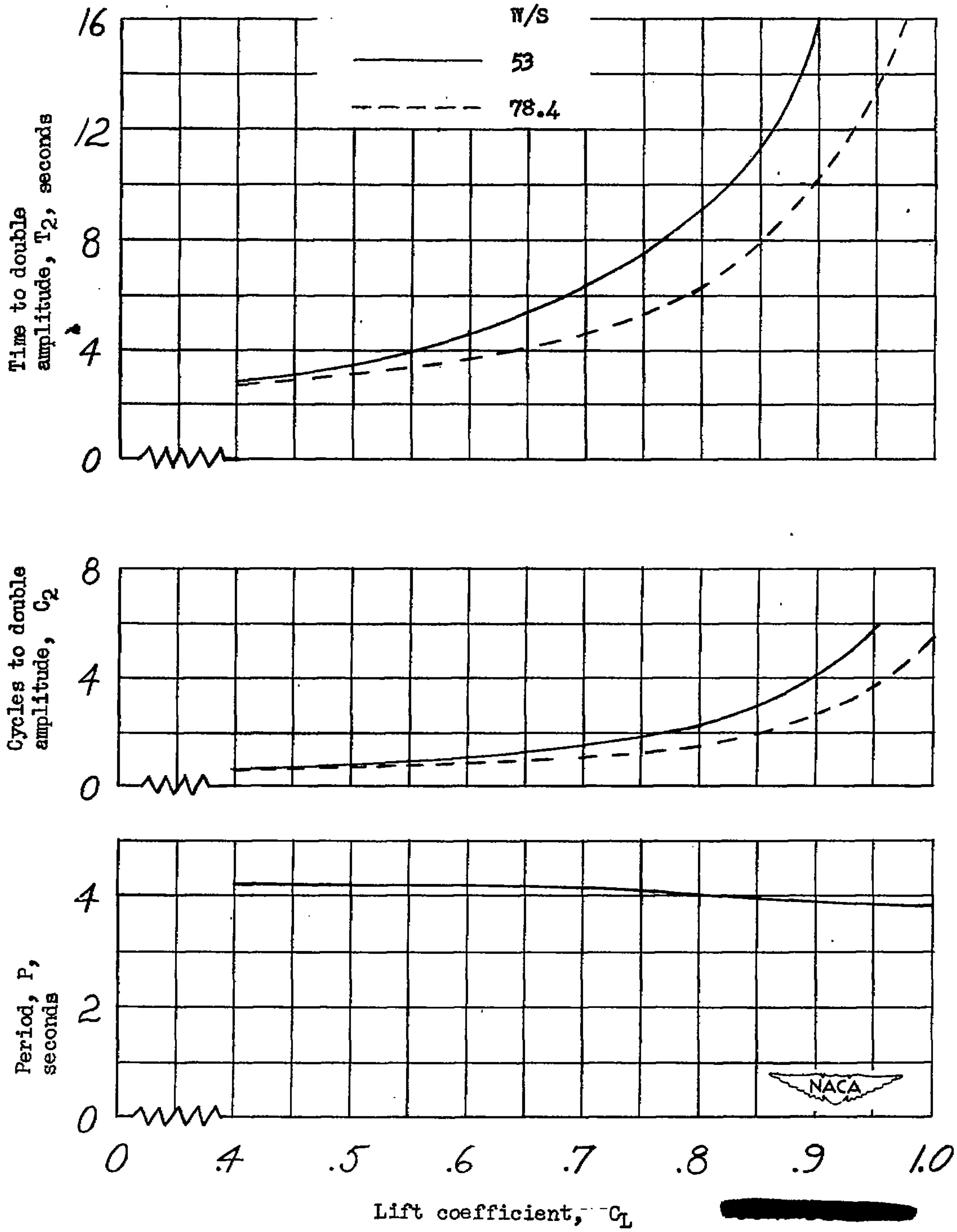
[redacted]



[redacted]

Figure 8.— Effects of wing loading on the oscillatory-stability boundary for sea-level flight. Flaps and gear down; $\delta_f = 50^{\circ}$.

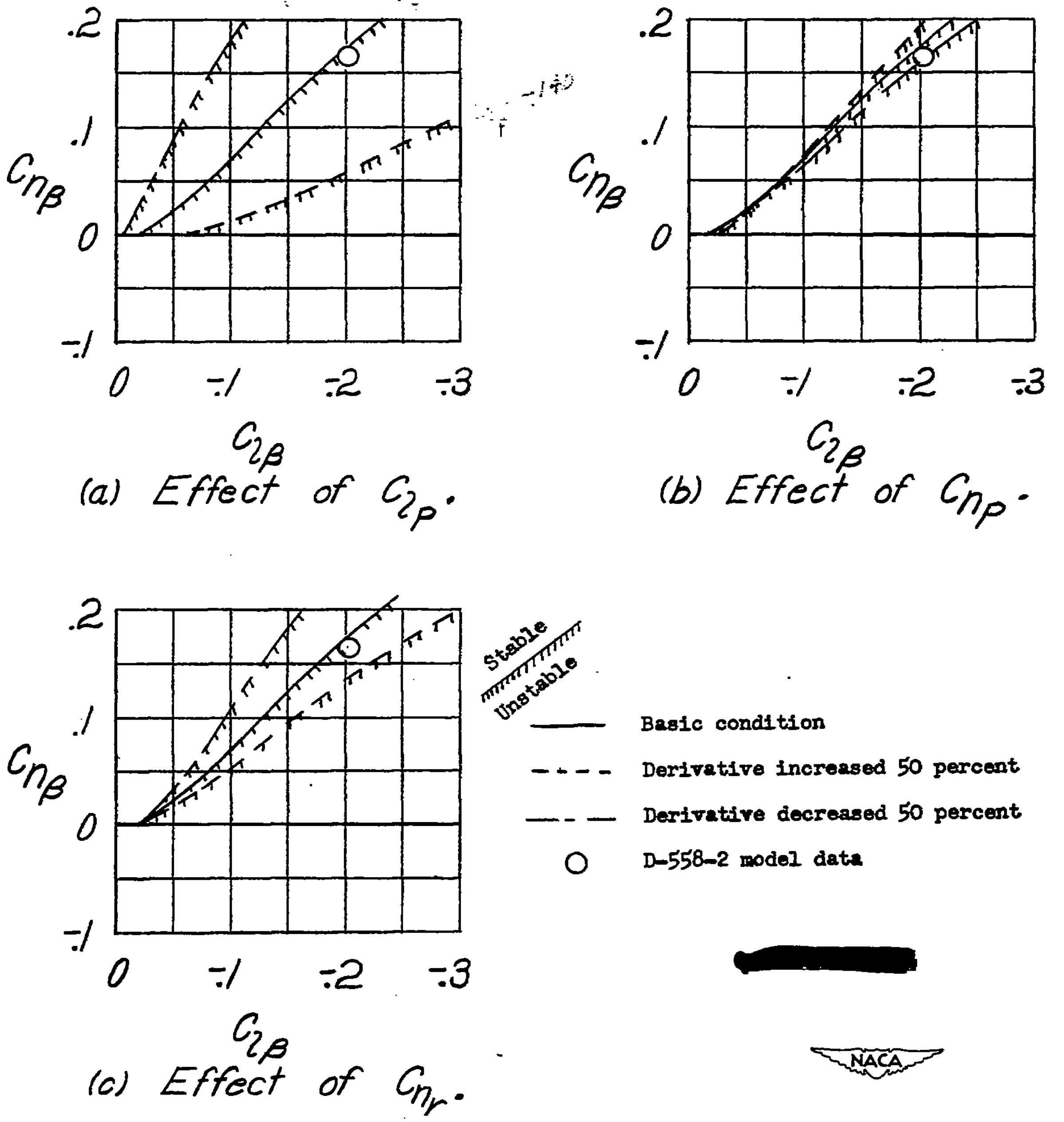
[redacted]



[redacted]

Figure 9.– Effects of wing loading on the period and damping of the lateral oscillation for sea-level flight. Flaps and gear down; $\delta_f = 50^{\circ}$.

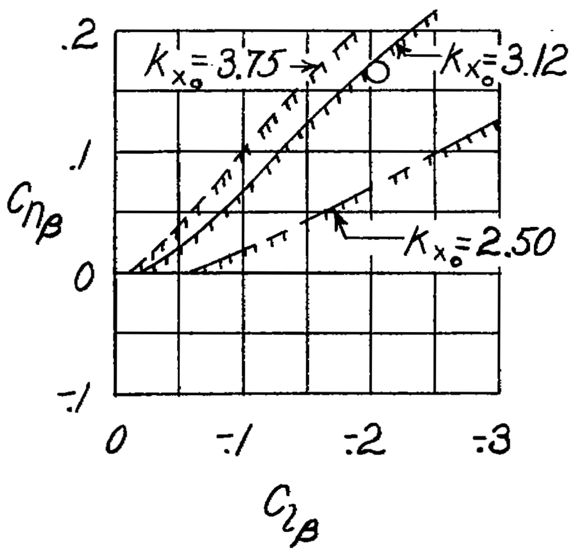
[redacted]



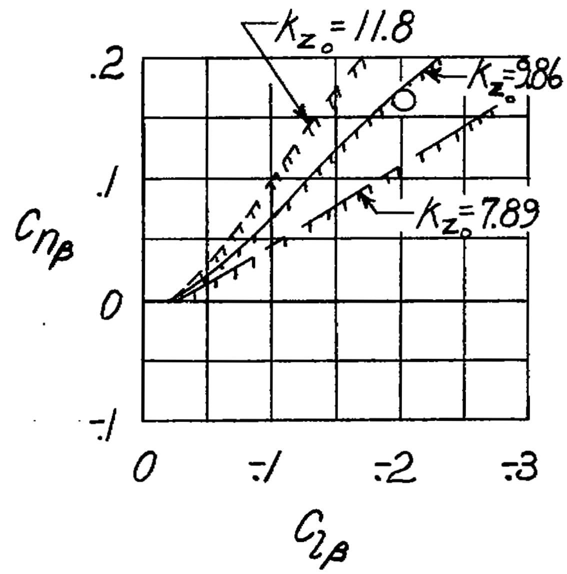
[redacted]

Figure 10.– Effects of variations of C_{l_p}, C_{n_p}, C_{n_r}, k_{X_0}, k_{Z_0}, and η on the oscillatory-stability boundary for sea-level flight. $\frac{W}{S} = 45.5$; flaps and gear down; $C_L = 1.0$.

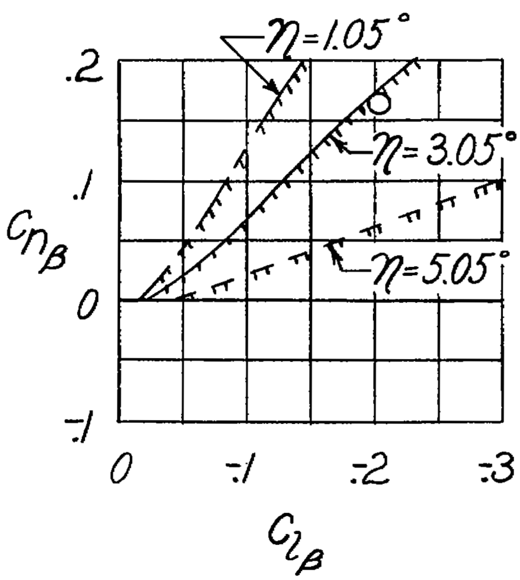
[redacted]



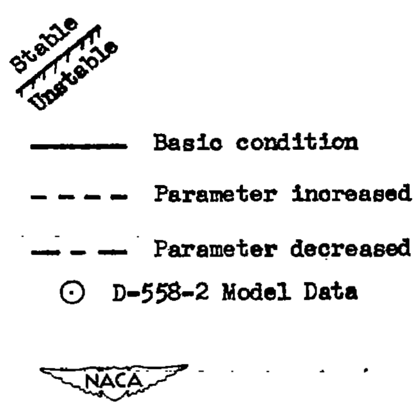
(d) Effect of k_{x_o}.



(e) Effect of k_{z_o}.



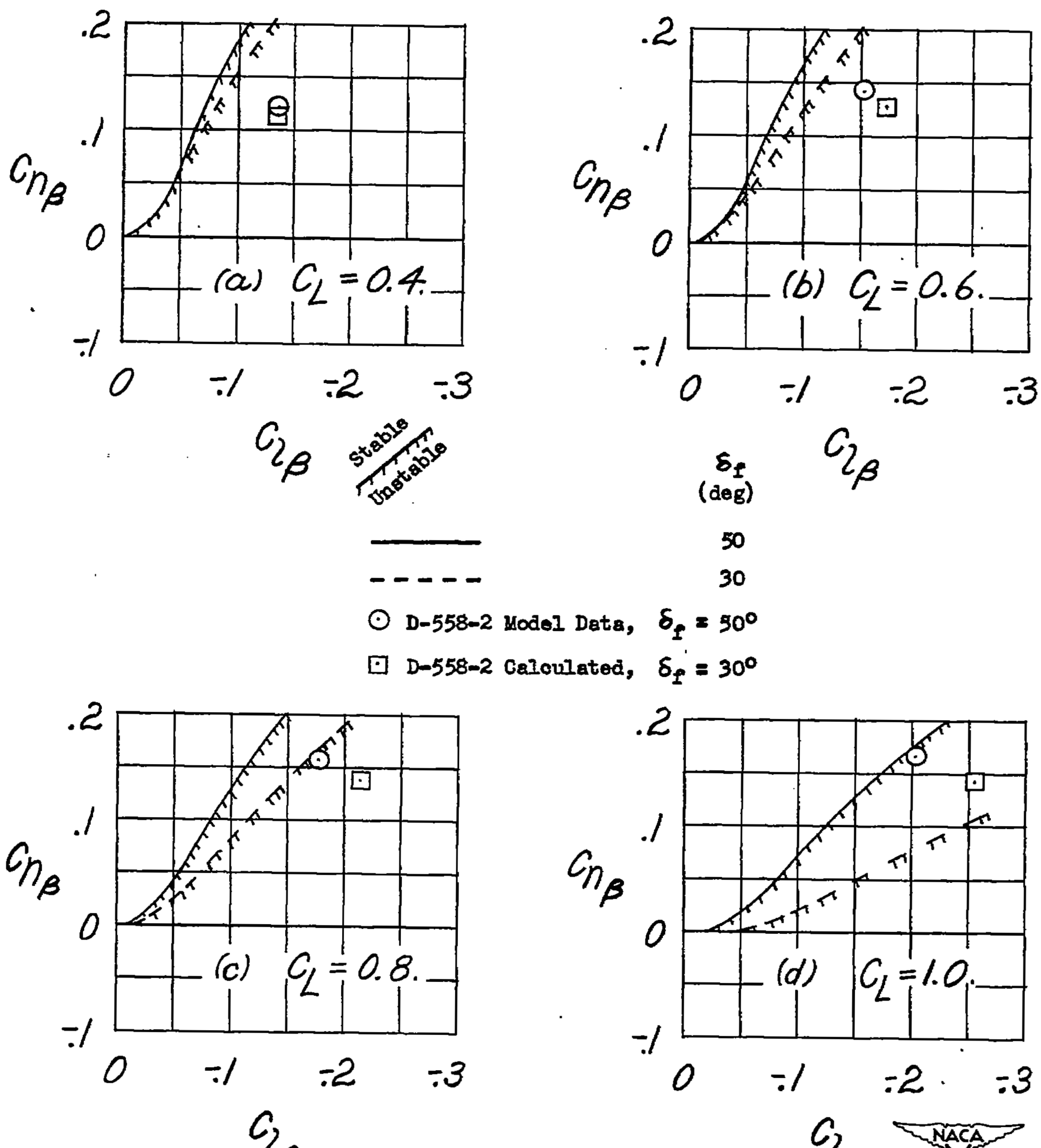
(f) Effect of η.



[redacted]

Figure 10.– Concluded.

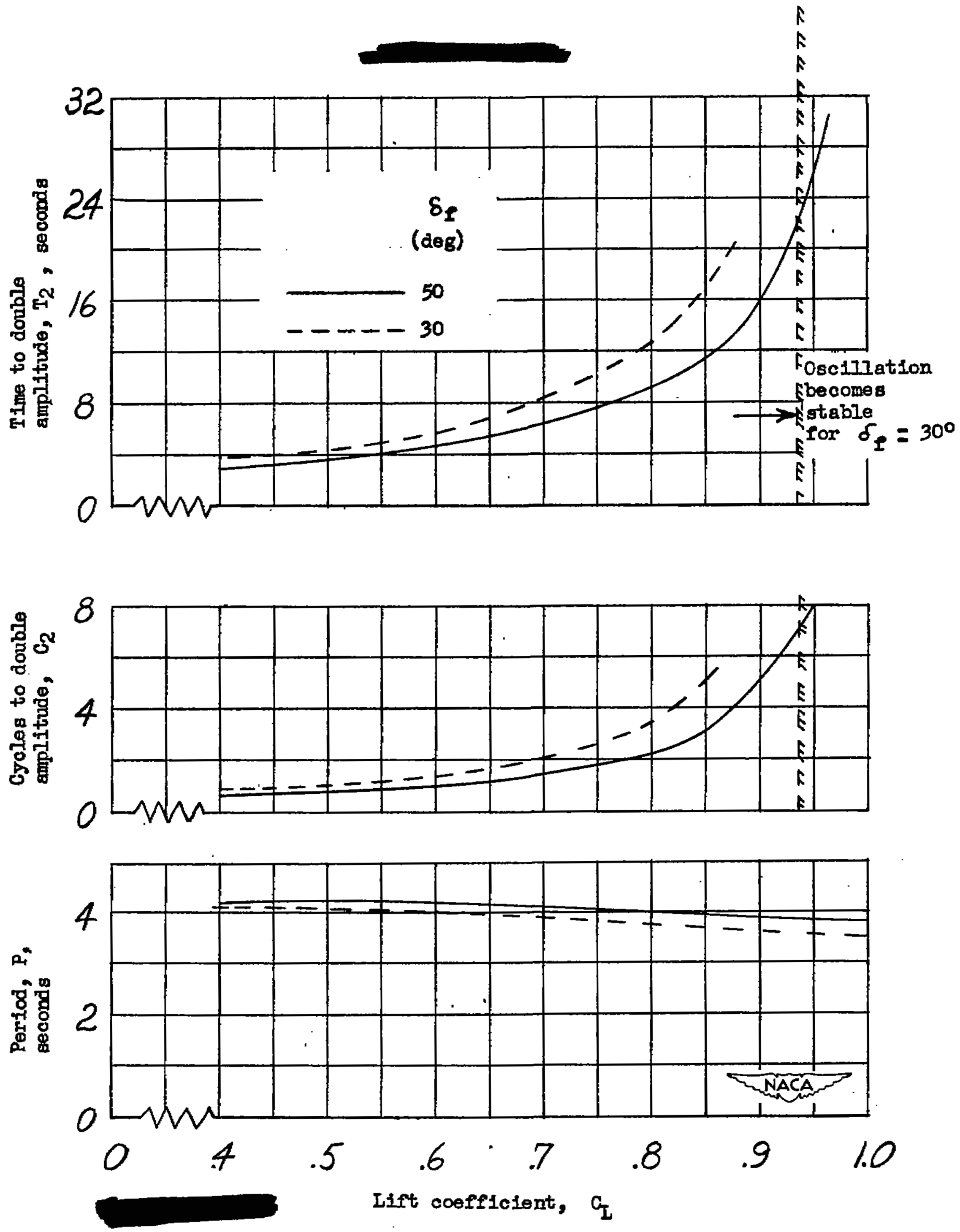
[redacted]



[redacted]

Figure 11.– Effects on the oscillatory-stability boundaries of reducing the flap deflection from 50° to 30°; sea-level flight; $\frac{W}{S} = 53.0$; flaps and gear down.

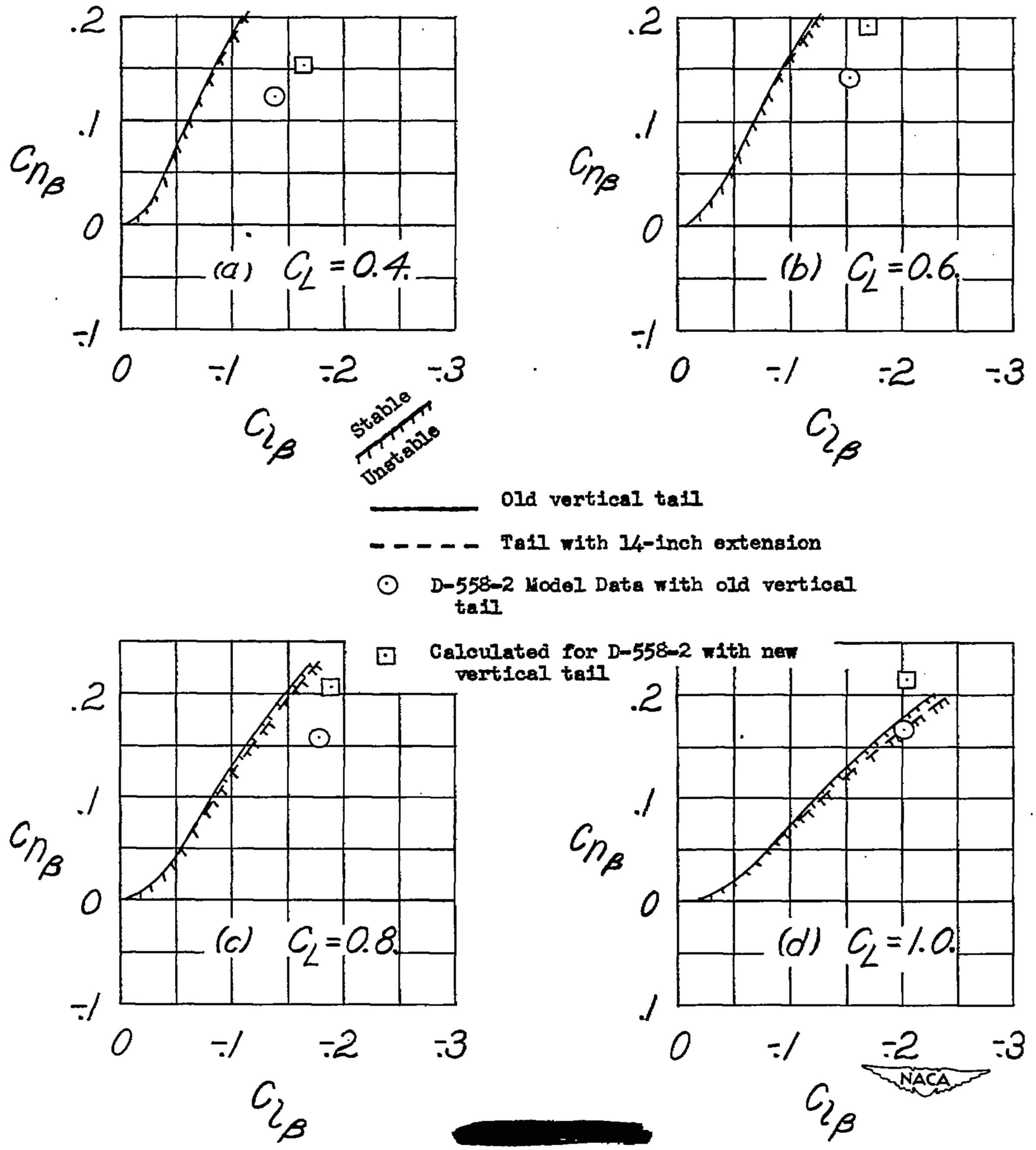
[redacted]



[redacted]

Figure 12.– Effects of flap deflection on the period and damping of the lateral oscillation. Sea-level flight; $\frac{W}{S}$ = 53.0.

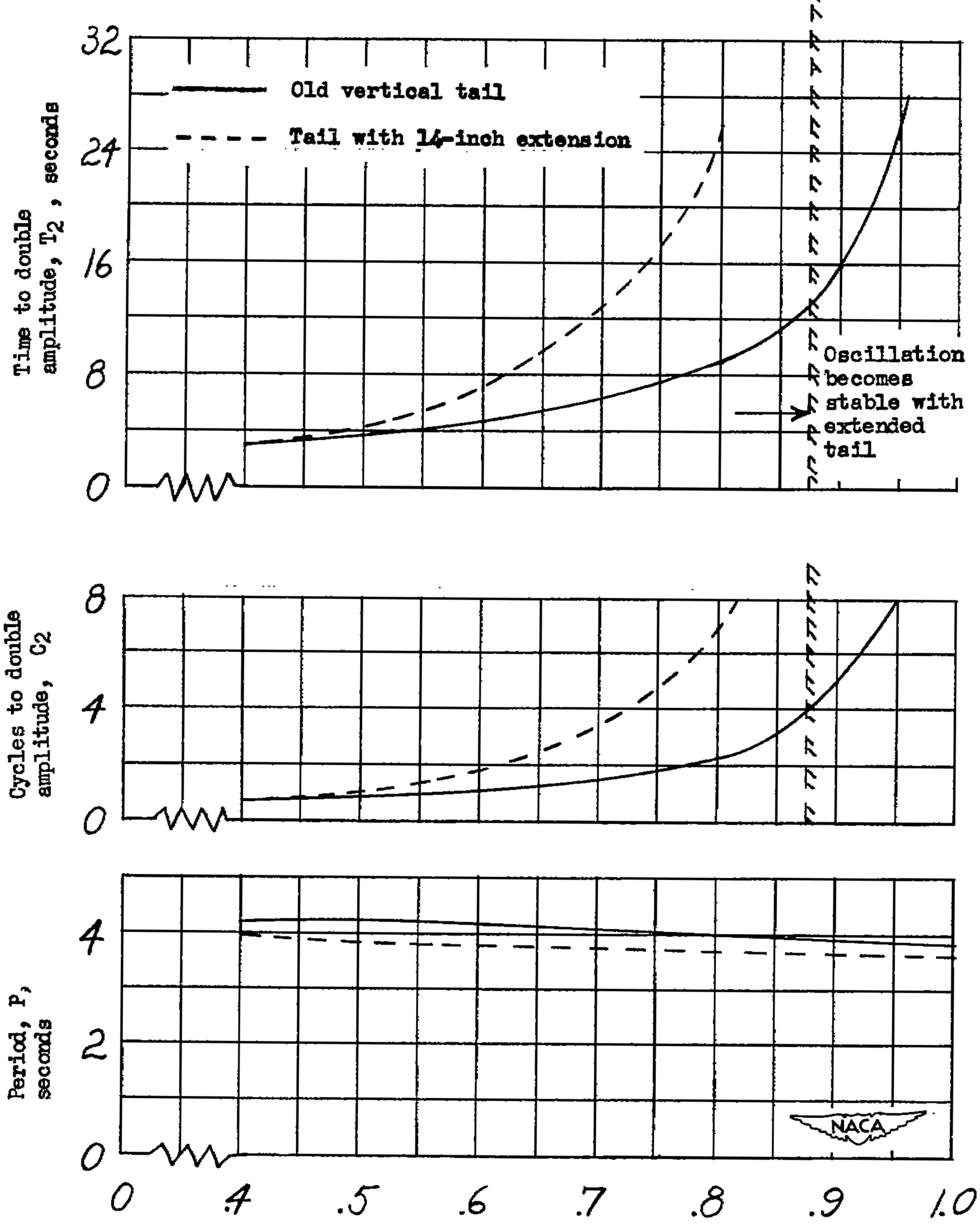
[redacted]



[redacted]

Figure 13.– Effects on the oscillatory-stability boundaries of increasing the vertical-tail height by 14 inches. Sea-level flight; $\frac{W}{S} = 53.0$; flaps and gear down.

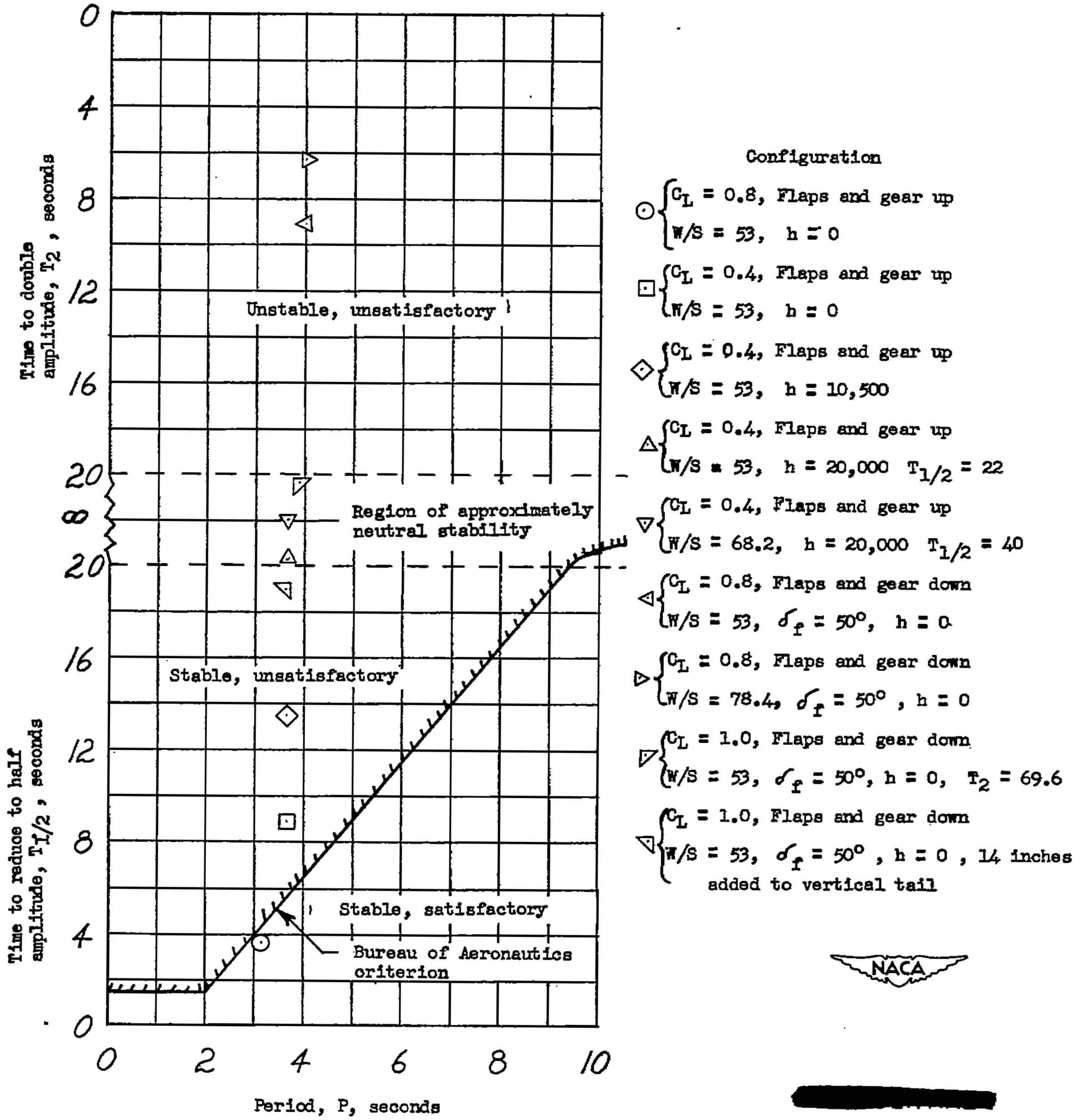
[redacted]



[redacted]

Figure 14.– Effects of increasing the vertical-tail height on the period and damping of the lateral oscillation. Sea-level flight; $\frac{W}{S} = 53.0$; flaps and gear down; $\delta_f = 50^{\circ}$.

[redacted]



[redacted]

Figure 15.– Comparison of calculated damping characteristics for several configurations of the D-558-2 airplane with the Bureau of Aeronautics criterion for satisfactory damping.